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Effect of Gradations of Sand on The Strength of Cement Mortar

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EFFECT OF GRADATIONS OF SAND ON THE STRENGTH OF CEMENT MORTAR

BY

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CHARLES ERNEST RAMSER and GEORGE SILAS RUSSELL

ENTITLED THE EFFECT OF GRADATIONS OF SAND ON THE STRENGTH OF CEMENT MORTAR

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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I N T R O D U C T I O N .

In the past the engineering profession has devoted much time and money in its endeavor to secure the highest attainable degree of perfection of Portland cement. The work along this line has met with great success and to-day the quality of American manufactured Portland cement has very little room for improvement. While it is no more than natural that the investigation of sands and concrete aggregate should go hand in hand with that of cement, they seem to have been almost entirely disregarded.

The first paper of any note treating upon this subject was written by Henry S. Spackman and Robert W. Lesley and read before the American Society of Testing Materials, June 23, 1908. The purpose of this paper was: to emphasize the fact that the strength of cement mortars and of concrete is as much dependent on the sand as on the cement; to show the necessity of careful and systematic inspection of the sand, as well as the cement, on all important construction; to suggest the desirability of standard specifications for and standard methods of testing sand, similar to those now adopted for testing cement.

This paper no doubt furnishes an excellent beginning for investigation along these lines, but the number of experi-

ments performed is entirely inadequate to deduce therefrom specifications for universal practice. Such specifications would require extensive experimental work throughout the cement laboratories of the United States, and would undoubtedly be an extremely valuable contribution to the engineering profession.

The University of Illinois, in the past few years, has been attempting to contribute something to the necessary experimental data. This work has been carried on by students in their thesis work, chiefly with Illinois sands. J. W. McManus, 1907, investigated "The Relative Value of Different Sands for Making Mortar" and, in the following year, E. B. Adams made extensive experiments on "the Mortar Making Qualities of Illinois Sands."

The purpose of this thesis is to continue this research work, and if possible to contribute some data towards its advancement. In the theses of previous years, natural sands were used throughout, no artificial gradation being employed. In this thesis, a deviation from this plan has been adopted in that fewer sands are used, but seven or eight artificial gradations are made from each sand. The gradations used were obtained from the results of extensive tests made by J. Y. Jewett for the American Society of Testing Materials, in which tensile tests were made on a single sand for seventy different gradations. These were divided into seven groups of ten each, according to their rank in the ninety day test, and the fifth gradation of each group was taken as an average of that group. By this method

gradations fairly representative of the entire number of seventy tests were obtained. In a few instances, it was found necessary to deviate slightly from the adopted gradations owing to the insufficient supply of sand. The sizes used in the gradations are as follows: Passing #10 and retained on #20; passing #20 and retained on #30; passing #30 and retained on #60; passing #60 and retained on #100; passing #100 and retained on pan; in which the number given refers to the number of meshes per linear inch.

The following sands were used: Platte River and Clear Creek, from Denver, Colo.; Wymore, from Wymore, Neb.; and Wabash, from the Wabash River. Ottawa sand was used for comparative tests. The Colorado sands are extensively used in construction work throughout the state. The Wabash sand is being used almost exclusively in all tests requiring sand at the University of Illinois.

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DESCRIPTION OF TESTS.

Three tests were made on each gradation of each sand: for specific gravity, tensile strength and voids. In addition to these the natural sands were tested for fineness. All sands were thoroughly dried before being used. The method of procedure in conducting these tests will now be described in detail.

SPECIFIC GRAVITY TEST:-In this test, Le Chatelier's apparatus was used. It consists of a flask of 120 cu. cm. capacity, into the neck of which is inserted a tube 9 mm. in diameter graduated up to a hundred cubic centimeters in tenths. The upper end of this tube is funnel shaped to facilitate the introduction of the sand. This apparatus is set upon a wooden stand. The stand has a vertical rod, at the top of which is a horizontal projecting arm with a clamp at the end which supports the tube. In determining the specific gravity, the flask and tube are first filled with water up to, or a little above, the zero mark. The temperature of the water should be about the same as that of the room. One hundred grams of sand are then introduced rapidly into the tube and, as soon as the water is clear enough, a reading taken. The difference between the initial and final readings, gives the quantity of water (in cubic centimeters) displaced by the sand, or it is the weight of the water in grams. From this data the specific gravity is readily deduced: being

the quantity obtained by dividing one hundred grams, the weight of the sand, by the weight of the displaced water in grams. In conducting this experiment, extreme care should be exercised in preventing the occurrence of air bubbles. If many air bubbles are formed that cannot be easily and quickly broken up, the experiment should be repeated. The results of these tests are shown complete in Table III.

TEST FOR VOIDS:-A very simple but comparatively accurate method was employed for determining the voids in the sand. A glass graduate is first weighed and then filled to the five hundred cubic centimeter mark with sand. The combined weight of graduate and contents is then ascertained and the difference in the two weights gives the weight of the sand in the graduate. If there were no voids in the sand, the weight would be equivalent to the specific gravity times 500 grams, the weight of 500 cubic centimeters of water. By subtracting the weight of the sand from the theoretical weight with no voids, the difference will give the weight of sand required to fill the voids. This difference, divided by the weight for no voids, gives the desired per cent of voids. For results of this test, see Table IV.

TEST FOR FINENESS:-The Per Se Testing Agitating Machine was used to determine the fineness of the sand. It is a standard sand sifting machine manufactured by the Howard and Morse Company, of Brooklyn, N. Y., is operated by a small induction motor

at a rate of 100 revolutions per minute and has a combined vertical and circular motion, the vertical drop being one half inch. This motion corresponds very closely to that obtained by hand sifting. The following sieves were used in the fineness test: Numbers 8, 10, 16, 20, 30, 40, 60, 74, 100, 150 and 200, the number of meshes per linear inch being indicated by the number of the sieve. A fineness test was made on a thousand grams of each sand. This amount was sifted for a period of forty minutes. The sieves were then taken out of the machine and the quantity of sand retained on each sieve and that caught by the pan was carefully weighed and recorded. From this data the percentages of the original charge was easily computed. Results of these tests are shown in Table I.

TEST FOR TENSILE STRENGTH:-For these tests Chicago A A Portland Cement was adopted for use. It was thoroughly tested and found to conform in every respect to the recently published specifications on cement of the American Society for Testing Materials. The proportions used for the mixture were: one part cement to three parts of sand by weight. The water required to obtain the proper plasticity constituted 9.7% of the combined weight of the cement and sand.

In the mixing, only sufficient material was mixed at one time to make six briquettes. By using a small quantity, the mixer was able to develop and maintain a more nearly uniform

method of mixing and consequently produce more uniform results. The sand and cement were mixed dry on a non-absorbing slate surface, which was well dampened prior to use. A crater was then formed in the center, into which the proper percentage of clean water was poured; the material on the outer edge was then turned into the crater by means of a trowel. As soon as the water had been absorbed, the material was mixed six times with the trowel before being molded. The form of mold used and the method of moulding are those recommended by the American Society of Civil Engineers. The molds were filled immediately after mixing, the material being firmly pressed in with the fingers and smoothed off with the trowel without resorting to mechanical ramming.

When the briquettes had been molded, they were marked for future identification. They were then covered with a damp cloth and allowed to stand twenty-four hours. At the end of this time the briquettes were removed from the molds and immersed in water at a temperature of 21° Centigrade. Here they were left until time for testing—seven, twenty-eight or ninety days. Six briquettes were made for each test, and the five most consistent results recorded. For the twenty-eight and ninety day test a Riehle automatic testing machine was used and for the seven day, the Fairbanks automatic. These are both standard machines. The load was applied to the briquettes at the rate of six hundred pounds per minute.

TABLE I.

RESULTS OF FINENESS TESTS.

Per cent retained on sieve no	Name of Sand			
	Wabash	Wymore	Platte	Cl.Creek
8	15.3	2.5	10.3	3.4
10	8.8	1.0	7.9	4.0
16	25.8	6.1	22.0	18.5
20	5.4	1.7	3.7	5.1
30	18.5	11.2	15.8	22.1
40	10.2	24.4	12.9	18.8
60	10.4	40.6	17.3	20.3
74	2.0	5.1	2.6	3.4
100	2.1	5.3	5.3	3.3
150	0.1	1.0	0.4	0.1
200	0.2	0.2	0.5	0.3
Pan	1.0	0.5	0.8	0.5
Total	99.8	99.6	99.5	99.8

Throughout the following tables the letter refers to the kind of sand used and the number to the gradation. The subscript "N" denotes natural sands used.

TABLE II.

ARTIFICIAL GRADATIONS USED.

Grad. No.	Per cent retained on sieve no.						
	10	20	30	60	100	Pan	Total
1	3	90	1	1	2	3	100
2	30	24	18	12	6	10	100
3	18	24	30	10	6	12	100
4	4	40	20	16	12	8	100
5	8	4	40	20	16	12	100
6	20	5	11	16	21	27	100
7	18	12	6	12.5	30	21.5	100
8	0	0	0	100	0	0	100
9	30	24	18	12	16	0	100
10	18	24	30	10	15	3	100
11	3	9	40	20	28	0	100
12	0	18	18	64	0	0	100
13	0	0	100	0	0	0	100
14	50	25	25	0	0	0	100

Throughout the following tables the letter refers to the kind of sand used and the number to the gradation. The subscript "N" denotes natural sand used. For example, W8, denotes Wymore sand, graded as shown in line 8, table II.

TABLE III.

RESULTS OF SPECIFIC GRAVITY TESTS.

Sand No.	Grams of sand used	Cu. cm. water displaced	Specific gravity
An	100	37.70	2.65
A1	"	37.70	2.65
A2	"	37.86	2.64
A4	"	37.68	2.65
A8	"	37.62	2.66
A10	"	37.51	2.66
A13	"	37.74	2.65
A14	"	37.60	2.66
Cn	"	38.70	2.58
C1	"	38.95	2.56
C2	"	38.97	2.56
C4	"	38.95	2.56
C8	"	38.72	2.58
C10	"	38.70	2.58
C13	"	38.65	2.59
C14	"	38.95	2.56
Pn	"	38.48	2.60
P1	"	38.32	2.61
P2	"	38.21	2.62
P3	"	38.23	2.62
P4	"	38.11	2.62
P5	"	38.10	2.62
P7	"	37.70	2.65
P8	"	38.39	2.60
P13	"	38.45	2.59
Wn	"	38.05	2.62
W4	"	38.50	2.60
W7	"	38.30	2.61
W8	"	38.25	2.62
W9	"	38.18	2.62
W10	"	38.18	2.62
W11	"	38.25	2.62
W12	"	38.25	2.62
W13	"	38.18	2.62
O	"	37.80	2.64

TABLE IV.
RESULTS OF TESTS FOR VOIDS.

Sand No	Wt. of 500c.c. of sand	Specific gravity	Per cent of voids
AH	890	2.65	32.8
A1	840	2.65	36.6
A2	944	2.64	28.5
A4	895	2.65	32.5
A8	770	2.66	42.1
A10	917	2.66	31.1
A13	767	2.65	42.1
A14	875	2.66	34.2
CH	795	2.58	38.4
C1	764	2.56	40.3
C2	868	2.56	32.2
C4	845	2.56	34.0
C8	700	2.58	45.7
C10	862	2.58	33.1
C13	722	2.59	44.2
C14	830	2.56	37.5
PH	883	2.60	32.1
P1	795	2.61	39.1
P2	928	2.62	29.1
P3	872	2.62	33.4
P4	853	2.62	34.9
P5	815	2.62	37.8
P7	919	2.65	30.6
P8	825	2.60	36.6
P13	812	2.59	37.5
WH	830	2.62	36.6
W4	862	2.60	33.7
W7	933	2.61	28.5
W8	770	2.62	41.2
W9	910	2.62	30.6
W10	905	2.62	30.9
W11	860	2.62	34.4
W12	817	2.62	37.6
W13	778	2.62	40.8
O	905	2.64	31.4

RESULTS OF TENSILE TESTS.

TABLE V.

WABASH. - A_N.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	24.1	31.2	18.5	20.6	4.1	1.3	99.8

Voids: 32.8%. Specific Gravity: 2.65.

Ref	Tensile Strength lbs/sq. in.		
No	Age 7dys	Age 28dys	Age 90dys.
1	208	275	410
2	203	235	390
3	202	315	385
4	213	248	312
5	205	240	403
Av.	206	263	382

TABLE VI.

WABASH. - A1.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	3	90	1	1	2	3	100

Voids: 36.6%. Specific Gravity: 2.65.

Ref.	Tensile Strength lbs./sq. in.		
No.	Age 7dys.	Age 28dys.	Age 90dys
1	178	204	302
2	138	225	340
3	169	162	330
4	181	184	330
5	160	223	310
Av.	165	200	322

RESULTS OF TENSILE TESTS.

TABLE VII.

WABASH. - A2.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	30	24	18	12	6	10	100

Voids: 28.5%. Specific Gravity: 2.64.

Ref.	Tensile Strength lbs/sq. in.		
No.	Age 7 dys.	Age 28 dys	Age 90 dys
1	153	217	287
2	153	251	295
3	138	217	272
4	158	230	297
5	133	262	288
Av.	147	235	288

TABLE VIII.

WABASH. - A4.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	4	40	20	16	12	8	100

Voids: 32.5%. Specific Gravity: 2.65.

Ref.	Tensile Strength lbs/sq. in.		
No.	Age 7 dys.	Age 28 dys.	Age 90 dys.
1	141	154	272
2	159	160	280
3	136	181	287
4	167	176	258
5	161	154	260
Av.	153	165	271

RESULTS OF TENSILE TESTS.

TABLE IX.

WABASH. - A8.

Sieve No	10	20	30	60	100	Pan	Tot.
o/o retained	0	0	0	100	0	0	100

Voids: 42.1%. Specific Gravity: 2.66.

Ref.	Tensile Strength lbs./sq. in.		
No.	Age 7dys	Age 28dys	Age 90dys
1	122	139	220
2	126	147	228
3	119	139	235
4	108	150	220
5	103	150	220
Av.	118	145	225

TABLE X.

WABASH. - A10.

Sieve No	10	20	30	60	100	Pan	Tot.
o/o retained	18	24	30	10	15	3	100

Voids: 31.1%. Specific Gravity: 2.66.

Ref.	Tensile Strength lbs/sq. in.		
No.	Age 7dys.	Age 28dys	Age 90dys.
1	157	210	278
2	164	240	298
3	166	190	285
4	161	190	285
5	166	190	260
Av.	163	204	281

RESULTS OF TENSILE TESTS.

TABLE XI.

WABASH. - A13.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	0	0	100	0	0	0	100

Voids: 42.1%. Specific Gravity: 2.65.

Ref.	Tensile Strength lbs./sq. in.		
No	Age 7dys.	Age 28dys.	Age 90dys.
1	120	190	257
2	129	190	255
3	123	173	263
4	135	170	262
5	131	190	290
Av.	128	183	265

TABLE XII.

WABASH. - A14.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	50	25	25	0	0	0	100

Voids: 34.2%. Specific Gravity: 2.66.

Ref.	Tensile Strength lbs/sq in		
No.	Age 7dys.	Age 28dys	Age 90dys.
	228	250	390
	239	250	378
	218	248	400
	200	275	372
	211	290	382
	219	263	384

RESULTS OF TENSILE TESTS.

TABLE XIII.

CLEAR CREEK. - Cn.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	7.4	23.6	22.1	39.1	6.7	0.9	99.8

Voids: 38.4%. Specific Gravity: 2.58.

Ref.	Tensile Strength lbs/sq. in.		
No.	Age 7dys.	Age 28dys	Age 90dys
1	125	170	260
2	128	168	235
3	120	180	245
4	125	168	252
5	130	185	252
Av.	126	174	249

TABLE XIV.

CLEAR CREEK. - C1.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	3	90	1	1	2	3	100

Voids: 40.3%. Specific Gravity: 2.56.

Ref.	Tensile Strength lbs/sq. in.		
No	Age 7dys	Age 28dys	Age 90dys
1	112	152	245
2	108	152	210
3	110	152	212
4	110	126	230
5	103	138	220
Av.	109	144	223

RESULTS OF TENSILE TESTS.

TABLE XV.

CLEAR CREEK. - C2.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	30	24	18	12	6	10	100

Voids: 32.2%. Specific Gravity: 2.56.

Ref.	Tensile Strength lbs./sq.in.		
No.	Age 7dys.	Age 28dys.	Age 90dys.
1	110	150	215
2	115	140	207
3	118	155	190
4	100	128	212
5	109	152	240
Av.	110	145	213

TABLE XVI.

CLEAR CREEK. - C4.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	4	40	20	16	12	8	100

Voids: 34.0%. Specific Gravity: 2.56.

Ref.	Tensile Strength lbs./sq.in.		
No.	Age 7 dys.	Age 28dys	Age 90dys.
1	122	150	190
2	96	145	200
3	102	149	197
4	116	140	192
5	99	150	192
Av.	107	147	194

RESULTS OF TENSILE TESTS.

TABLE XVII.

CLEAR CREEK. - C8.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	0	0	0	100	0	0	100

Voids: 45.7%. Specific Gravity: 2.58.

Ref.	Tensile Strength lbs/sq. in.		
No.	Age 7dys.	Age 28dys.	Age 90dys.
1	74	132	175
2	79	125	177
3	79	120	185
4	79	118	175
5	73	132	175
Av.	77	125	177

TABLE XVIII.

CLEAR CREEK. - C10.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	18	24	30	10	15	3	100

Voids: 33.1%. Specific Gravity: 2.58.

Ref.	Tensile Strength lbs./sq. in.		
No.	Age 7dys.	Age 28dys.	Age 90dys.
1	105	153	250
2	111	160	202
3	109	158	225
4	112	147	227
5	135	152	235
Av.	114	154	228

RESULTS OF TENSILE TESTS.

TABLE XIX.

CLEAR CREEK. - C13.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	0	0	100	0	0	0	100

Voids: 44.2%. Specific Gravity: 2.59.

Ref.	Tensile Strength lbs/sq. in.		
No.	Age 7 dys.	Age 28dys.	Age 90dys.
1	110	155	200
2	108	152	195
3	110	140	198
4	108	135	190
5	111	135	202
Av.	109	144	197

TABLE XX.

CLEAR CREEK. - C14.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	50	25	25	0	0	0	100

Voids: 37.5%. Specific Gravity: 2.56.

Ref.	Tensile Strength lbs/sq. in.		
No.	Age 7dys	Age 28dys	Age 90dys
1	153	210	267
2	129	185	255
3	145	212	308
4	137	212	280
5	148	192	290
Av.	142	202	280

RESULTS OF TENSILE TESTS.

TABLE XXI.

PLATTE. - PN.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	18.2	25.7	15.8	30.2	7.9	1.7	99.5

Voids: 32.1%. Specific Gravity: 2.60.

Ref.	Tensile Strength lbs./sq. in.		
No.	Age 7dys	Age 28dys	Age 90dys
1	120	220	303
2	132	206	249
3	132	215	251
4	154	209	262
5	143	218	270
Av.	136	214	267

TABLE XXII.

PLATTE. P1.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	3	90	1	1	2	3	100

Voids: 39.1%. Specific Gravity: 2.61.

Ref.	Tensile Strength lbs/sq. in.		
No.	Age 7dys.	Age 28dys	Age 90dys
1	124	200	278
2	122	180	282
3	149	205	250
4	131	203	248
5	140	208	275
Av.	133	197	267

RESULTS OF TENSILE TESTS.

TABLE XXIII.

PLATTE. - P2.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	30	24	18	12	6	10	100

Voids: 29.1%. Specific Gravity: 2.62.

Ref.	Tensile Strength lbs./sq.in.		
No.	Age 7dys	Age 28dys	Age 90dys
1	133	147	300
2	146	205	280
3	143	193	280
4	142	152	305
5	121	220	285
Av.	137	183	290

TABLE XXIV.

PLATTE. - P3.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	18	24	30	10	6	12	100

Voids: 33.4%. Specific Gravity: 2.62.

Ref.	Tensile Strength lbs/sq in		
No.	Age 7dys.	Age 28dys.	Age 90dys.
1	140	178	245
2	124	165	260
3	121	175	270
4	131	168	258
5	124	170	270
Av.	128	171	261

RESULTS OF TENSILE TESTS.

TABLE XXV.

PLATTE. - P4.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	4	40	20	16	12	8	100

Voids: 34.9%. Specific Gravity: 2.62.

Ref.	Tensile Strength lbs./sq.in.		
No.	Age 7dys.	Age 28dys.	Age 90dys.
1	137	145	260
2	127	155	272
3	136	155	258
4	120	140	255
5	121	151	258
Av	128	149	261

TABLE XXVI.

PLATTE. - P5.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	8	4	40	20	16	12	100

Voids: 37.8%. Specific Gravity: 2.62.

Ref.	Tensile Strength lbs/sq.in.		
No.	Age 7dys	Age 28dys	Age 90dys
1	109	143	205
2	113	145	217
3	123	141	210
4	137	137	202
5	120	130	200
Av.	120	139	207

RESULTS OF TENSILE TESTS.

TABLE XXVII.

PLATTE. - P7.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	18	12	6	12.5	30	21.5	100

Voids: 30.6%. Specific Gravity: 2.65.

Ref.	Tensile Strength lbs/sq.in.		
No.	Age 7dys.	Age 28dys.	Age 90dys.
1		121	180
2		141	182
3		117	185
4		121	170
5		140	182
Av.		128	180

TABLE XXVIII.

PLATTE. - P8.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	0	0	0	100	0	0	100

Voids: 36.6%. Specific Gravity: 2.60.

Ref.	Tensile Strength lbs/sq.in.		
No.	Age 7dys.	Age 28dys	Age 90dys
1	88	115	177
2	75	124	168
3	85	117	168
4	87	110	180
5	84	125	180
Av.	84	118	175

RESULTS OF TENSILE TESTS.

TABLE XXIX.

PLATTE. - P13.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	0	0	100	0	0	0	100

Voids: 37.5%. Specific Gravity: 2.59.

Ref.	Tensile Strength lbs/sq. in.		
No.	Age 7dys	Age 28dys	Age 90dys.
1	108	121	230
2	102	119	218
3	105	112	222
4	91	138	232
5	101	128	220
Av.	101	124	224

TABLE XXX.

WYMORE. - W_N.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	3.5	7.8	11.2	65.0	10.4	1.7	99.6

Voids: 36.6%. Specific Gravity: 2.62.

Ref.	Tensile Strength lbs/sq. in.		
No.	Age 7dys.	Age 28dys.	Age 90dys.
1	125	160	198
2	114	190	201
3	135	185	210
4	140	170	208
5	130	189	205
Av.	129	179	204

TABLE XXXI.

WYMORE. - W4.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	4	40	20	16	12	8	100

Voids: 33.7%. Specific Gravity: 2.60.

Ref.	Tensile Strength lbs/sq. in.		
No.	Age 7days	Age 28dys.	Age 90dys.
1		155	255
2		162	220
3		162	270
4		153	245
5		——	210
Av.		158	240

TABLE XXXII.

WYMORE. - W7.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	18	12	6	12.5	30	21.5	100

Voids: 28.5%. Specific Gravity: 2.61.

Ref.	Tensile Strength lbs/sq.in.		
No.	Age 7dys.	Age 28dys	Age 90dys.
1		125	200
2		125	188
3		125	205
4		133	192
5		120	196
Av.		126	196

RESULTS OF TENSILE TESTS.

TABLE XXXIII.

WYMORE. - W8.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	0	0	0	100	0	0	100

Voids: 41.2%   Specific Gravity: 2.62.

Ref.	Tensile Strength lbs/sq.in.		
No.	Age 7dys	Age 28dys	Age 90dys
1	87	107	151
2	86	100	175
3	91	107	150
4	92	112	160
5	88	116	150
Av.	89	108	157

TABLE XXXIV.

WYMORE. - W9.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	30	24	18	12	16	0	100

Voids: 30.6%.   Specific Gravity: 2.62.

Ref.	Tensile Strength lbs/sq.in.		
No.	Age 7dys	Age 28dys	Age 90dys
1		183	280
2		186	275
3		195	272
4		187	270
5		208	290
Av.		192	277

RESULTS OF TENSILE TESTS.

TABLE XXXV.

WYMORE. - W10.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	18	24	30	10	15	3	100

Voids: 30.9%. Specific Gravity: 2.62.

Ref.	Tensile Strength lbs/sq.in.		
No	Age 7 days	Age 28 dys.	Age 90 dys
1		190	325
2		192	303
3		183	295
4		198	275
5		187	288
Av.		190	297

TABLE XXXVI.

WYMORE. - W11.

Sieve no	10	20	30	60	100	Pan	Tot
o/o retained	3	9	40	20	28	0	100

Voids: 34.4%. Specific Gravity: 2.62.

Ref.	Tensile Strength lbs./sq.in.		
No.	Age 7 dys.	Age 28 dys.	Age 90 dys.
1		123	165
2		118	192
3		115	185
4		112	190
5		100	180
Av.		114	182

RESULTS OF TENSILE TESTS.

TABLE XXXVII.

WYMORE. - W12.

Sieve no	10	20	30	60	100	Pan	Tot.
o/o retained	0	18	18	64	0	0	100

Voids: 37.6%. Specific Gravity: 2.62.

Ref.	Tensile Strength lbs/sq.in.		
No.	Age 7dys.	Age 28dys.	Age 90dys.
1	112	110	175
2	104	128	180
3	100	132	190
4	102	125	160
5	101	128	175
Av.	104	125	176

TABLE XXXVIII.

WYMORE . - W13.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	0	0	100	0	0	0	100

Voids: 40.8%. Specific Gravity: 2.62.

Ref.	Tensile Strength lbs/sq in		
No.	Age 7dys.	Age 28dys	Age 90dys.
1			196
2			215
3			210
4			202
5			205
Av			206

RESULTS OF TENSILE TESTS.

TABLE XXXIX.

STANDARD OTTAWA SAND.

Sieve no.	10	20	30	60	100	Pan	Tot.
o/o retained	0	0	100	0	0	0	100

Voids: 31.4%. Specific Gravity: 2.64.

Ref.	Tensile Strength lbs/sq.in.		
No.	Age 7dys.	Age 28dys	Age 90dys.
1	155	245	345
2	145	237	345
3	147	242	340
4	154	242	350
5	140	240	370
Av	148	241	350

Standard Ottawa sand passes a #20 sieve and is retained on a #30 sieve. This corresponds to gradation 13 of the other sands.

TABLES FOR COMPARISON.-Seven Day Tests.

TABLE XL.

Ottawa: Voids, 31.4% Tensile Strength, 148.

Grad.	Per cent of Voids				Specific Gravity				Ten. Strength lbs/sq.in.			
No.	A	C	P	W	A	C	P	W	A	C	P	W
1	36.6	40.3	39.1	—	2.65	2.56	2.61	—	165	109	133	—
2	28.5	32.2	29.1	—	2.64	2.56	2.62	—	147	110	137	—
3	—	—	33.4	—	—	—	2.62	—	—	—	128	—
4	32.5	34.0	34.9	33.7	2.65	2.56	2.62	2.60	153	107	128	—
5	—	—	37.8	—	—	—	2.62	—	—	—	120	—
6	—	—	—	—	—	—	—	—	—	—	—	—
7	—	—	30.6	28.5	—	—	2.65	2.61	—	—	—	—
8	42.1	45.7	36.6	41.2	2.66	2.58	2.60	2.62	118	77	84	89
9	—	—	—	30.6	—	—	—	2.62	—	—	—	—
10	31.1	33.1	—	30.9	2.66	2.58	—	2.62	163	114	—	—
11	—	—	—	34.4	—	—	—	2.62	—	—	—	—
12	—	—	—	37.6	—	—	—	2.62	—	—	—	104
13	42.1	44.2	37.5	40.8	2.65	2.59	2.59	2.62	128	109	101	—
14	34.2	37.5	—	—	2.66	2.56	—	—	219	142	—	—
N	32.8	38.4	32.1	36.6	2.65	2.58	2.60	2.62	206	126	136	129

TABLES FOR COMPARISON.-Twenty-eight Day Tests.

TABLE XLI.

Ottawa: Voids, 31.4%. Tensile Strength, 241.

Grad.	Per cent of Voids				Specific Gravity				Ten. Strength lbs./sq in			
No.	A	C	P	W	A	C	P	W	A	C	P	W
1	36.6	40.3	39.1	—	2.65	2.56	2.61	—	200	144	197	—
2	28.5	32.2	29.1	—	2.64	2.56	2.62	—	235	145	183	—
3	—	—	33.4	—	—	—	2.62	—	—	—	171	—
4	32.5	34.0	34.9	33.7	2.65	2.56	2.62	2.60	165	147	149	158
5	—	—	37.8	—	—	—	2.62	—	—	—	139	—
6	—	—	—	—	—	—	—	—	—	—	—	—
7	—	—	30.6	28.5	—	—	2.65	2.61	—	—	128	126
8	42.1	45.7	36.6	41.2	2.66	2.58	2.60	2.62	145	125	118	108
9	—	—	—	30.6	—	—	—	2.62	—	—	—	192
10	31.1	33.1	—	30.9	2.66	2.58	—	2.62	204	154	—	190
11	—	—	—	34.4	—	—	—	2.62	—	—	—	114
12	—	—	—	37.6	—	—	—	2.62	—	—	—	125
13	42.1	44.2	37.5	40.8	2.65	2.59	2.59	2.62	183	144	124	—
14	34.2	37.5	—	—	2.66	2.56	—	—	263	202	—	—
M	32.8	38.4	32.1	36.6	2.65	2.58	2.60	2.62	2.63	174	214	179

TABLES FOR COMPARISON.-Ninety Day Tests.

TABLE XLII.

Ottawa: Voids, 31.4%. Tensile Strength, 350.

Grad.	Per cent of Voids				Specific Gravity				Ten Strength lbs/sq.in.			
No.	A	C	P	W	A	C	P	W	A	C	P	W
1	36.6	40.3	39.1	—	2.65	2.56	2.61	—	322	223	267	—
2	28.5	32.2	29.1	—	2.64	2.56	2.62	—	288	213	290	—
3	—	—	33.4	—	—	—	2.62	—	—	—	261	—
4	32.5	34.0	34.9	33.7	2.65	2.56	2.62	2.60	271	194	261	240
5	—	—	37.8	—	—	—	2.62	—	—	—	207	—
6	—	—	—	—	—	—	—	—	—	—	—	—
7	—	—	30.6	28.5	—	—	2.65	2.61	—	—	180	196
8	42.1	45.7	36.6	41.2	2.66	2.58	2.60	2.62	225	177	175	157
9	—	—	—	30.6	—	—	—	2.62	—	—	—	277
10	31.1	33.1	—	30.9	2.66	2.58	—	2.62	281	228	—	297
11	—	—	—	34.4	—	—	—	2.62	—	—	—	182
12	—	—	—	37.6	—	—	—	2.62	—	—	—	176
13	42.1	44.2	37.5	40.8	2.65	2.59	2.59	2.62	265	197	224	206
14	34.2	37.5	—	—	2.66	2.56	—	—	384	280	—	—
M	32.8	38.4	32.1	36.6	2.65	2.58	2.60	2.62	382	249	267	204

CONCLUSION.

The number of tests made for this thesis is not sufficient to lead to any definite conclusions; but the general trend of results may be discussed with special comparisons as to agreement or non-agreement with the results of authorities. The conclusions drawn by these experimenters are so widely varied that this thesis will only serve to give additional evidence along certain lines.

For specifications of sands, in the past, the following clause has usually been emphasized: "The sand shall be sharp, clean and coarse." These characteristics have been considered the primary, and in fact, the only requisites for good sand although it is sometimes stated, in addition, that the sand shall be composed of durable minerals, and the size of the grains shall be such as to give a minimum of voids.

It is natural to suppose that sharp sand is superior to sand with rounded grains. This is due to the fact that, the angular grains being rougher, the cement will adhere better; then too, the angular grains offer greater resistance to moving one on the other under compression. However, the sharper the sand, the greater the percentage of voids and the larger the amount of cement that will be required to produce a given density. From

the results of these tests, it is seen in Table XLII that Clear Creek sand, the sharpest of the four sands used, also has the largest percentage of voids and the lowest tensile strength. This may be attributed to aless degree of density accruing from the large per cent of voids; but another explanation worthy of consideration is that with sharp grains, the interstices are irregular and the cement does not get a good bond along the entire surface of the sand grain. The latter seems to be the more logical conclusion, for in the various tests made on this sand, those on C14, while having a larger percentage of voids than several of the other gradations, still remains the strongest throughout. However, if the interstices of sharp sand are practically filled, a better bond results and consequently a much greater tensile strength. Such results could probably be obtained, either by some improved method of mixing or by a greater amount of time and labor being expended in the present method.

It does not come within the province of this thesis to discuss the value of clean sand to mortar. However, it is worth while noting that a quantity of finely powdered clay up to ten per cent will not materially decrease the strength of the mortar. This has been borne out by numerous tests at the University of Illinois. The strongest sand used in these tests was Wabash sand and only a casual inspection was necessary to see that it contained a much larger percentage of clay or loamy matter than any of the other sands.

The third requisite for good sand is undoubtedly the most important of the three, and the significance of coarse grained sand is borne out by these tests. There are two reasons why coarse sands are preferable to fine: (1) coarse sands have less surface to cover and hence require less cement; (2) less labor is required to fill the interstices and, in practical work, the concrete is apt to be more thoroughly mixed. The gradations having the coarsest grains in these tests are 1, 2, 9 and 14 and these show up the strongest in tensile strength. For a direct comparison between the relative value of fine and coarse sands, it is only necessary to compare the results obtained from gradations number eight and thirteen for the same sands. Gradation number eight has one hundred per cent retained on a sixty and passing a forty sieve, and number thirteen has one hundred per cent retained on thirty and passing twenty. Since the voids are practically the same in both cases, the difference in tensile strength can readily be ascribed to the size of the grains. As to sands of more than one size of grain, it seems advisable to have a few varied sizes and "the coarser, the better" is undoubtedly the rule in this case. Since nearly all commercial sands have some fine grains, the coarsest sands will be the best, other things being equal. While coarse sands invariably give the greater tensile strengths, yet it may be observed from the tables on tensile strength that the more uniform results were obtained from the fine sands. This is due to a more uniform distribution of the

grains throughout the breaking section of the briquette. In practice, however, this would no doubt be overbalanced by the fact that the finer sands require much more tamping to secure these uniform results.

It will be noticed throughout these tests that there is a marked difference in relative position between the mixtures giving the lowest per cent of voids and those giving the highest tensile strength. This is diametrically opposite to the much advocated theory which claims that the greatest tensile strength obtains for a minimum of voids. J. Y. Jewett, in his comparatively extensive sand experiments arrived at the same conclusion and in his results states that the tensile strength is more largely dependent on the coarseness of the grains than on a low per cent of voids. In support of the void theory, on the other hand, Messrs. Humphrey and Jordan of the United States Testing Laboratory of St. Louis have made a large number of tests which they claim bear out this theory. There are still conflicting views along this line and the truth or fallacy of any theory can only be ascertained by a multiplicity of tests made throughout the laboratories of this country.